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THE AGE OF THE EARTH AND THE SALTNESS OF THE SEA

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Since the discovery of radioactivity, any estimation of geologic time from the process of secular cooling, or from calculations of the age of the sun's heat has become a process of very doubtful validity. That being so, enhanced interest now accrues to any method not based on these data. One of the most instructive of these is that of Professor Joly[1] based on the saltness of the sea. But, standing as it does on its own merits, and without collateral support, it is more than ever necessary to examine carefully the foundations on which it is based.

The analysis of rocks shows clearly that the proportion of sodium in the sedimentaries is much smaller than in the igneous rocks. The natural inference from this is that the balance is to be found in the ocean in the form of salt. Assuming these premises and a fairly uniform rate of erosion, the estimation of geologic time is reduced to a process of simple division. It is only necessary to find the total quantity of sodium in the sea and the amount brought down by the rivers each year. This, with some corrections, is Professor Joly's method. The corrections, according to his estimate, are not considerable and his calculation works out to something less than 100 millions of years.

The data for the two principal premises are derived from Sir John Murray.[2] This worker has carried out numerous investigations on ocean depths and has also made estimates of the amount of solvent denudation. That these are in the main fairly accurate can hardly be disputed; but, as applied by Professor Joly to an entirely different purpose, they are open to a number of criticisms.

For our present purpose we will accept Sir John Murray's estimate of the amount of the sodium in the sea; but the amount which enters into it each year is a much more doubtful quantity. Into all the sources of error it is not possible to enter here; but the following short summary will show that these are very great.

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[1] *Trans. Royal Society Dublin*, Vol. VII, pp. 26 f.

[2] See *Scottish Geographical Magazine* (1887), and elsewhere.

In the first place we must remember that sodium is a minor constituent in river waters. It is also, as every chemist knows, the most difficult of all to determine. Anyone who is acquainted with the many possibilities of error implicit in the process of boiling down considerable quantities of river water, removing all the other constituents in order to find in the end possibly two or three parts per million of sodium, will know that very little reliance should be placed on this part of an ordinary water analysis. In order to obtain results of any value for this constituent, great care and special precautions must be taken. So far is this from being the case in the average analysis, especially the older ones from which Sir John Murray's tables are constructed, that all the alkali metals are commonly determined together and stated as sodium and potassium.

Once more, Professor Joly makes an entirely inadequate allowance for cyclic salt. Sea salt, especially in stormy weather, continually passes into the air, is brought down by the rain, and is deposited in other ways. This is washed into the rivers and thus reaches the sea once more. Another form of cyclic salt is that known as fossil sea salt. This was deposited with the other constituents in the sedimentaries and is once more set free by erosion. As none of the ordinary rocks (with the exception of salt beds) contain any appreciable proportion of chlorine, it is highly probable that the greater part of the chlorine in river waters is cyclic in some form or other. This particular aspect has already been the subject of some controversy, and Professor Joly has admitted that he has probably underestimated the amount of cyclic salt; but he meets the difficulty by stating that there is a considerable preponderance of sodium in the river waters above the chlorine, and that, even assuming that all the chlorine is cyclic, the estimate of geologic time is not thereby raised to more than one hundred and forty millions of years.[1]

But, by this admission, the whole calculation is made to rest to a much greater extent on the minute accuracy of sodium analyses, which, as we have already seen, does not exist. To show what differences small errors can make, it is interesting to note that more recently another worker, M. Dubois, has made fresh calculations, using only the more accurate sodium analyses, and has obtained as the result four hundred millions of years.[1] I, for one, should not like to state dogmatically that one or other of these results is accurate; but certainly the calculation of Professor Dubois is the more reliable of the two. It is more instructive to note the reason why such diverse estimates are possible. This can be seen by anyone who refers to the original paper and makes a few simple calculations.

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[1] See discussion between Professor Joly and Mr. Acroyd, *Chemical News* (1901).

According to Sir John Murray's data, the percentage of sodium in river waters compared with the total dissolved solid is 3.47, that of chlorine 1.85.[2] Professor Joly's calculation assumes 10 per cent. of the chlorine to be cyclic. If we assume the amount of sodium to be 2.47 per cent. (an amount of error not at all unlikely to occur in these analyses, especially if calculated in a rough statistical way), and the more probable quantity of 90 per cent. of the chlorine to be cyclic, our estimate would be raised to two hundred and fifty millions of years. If the sodium were but 1.5 per cent. of the total solid, the estimate would be fifteen hundred and seventy millions of years. As we have seen, M. Dubois' estimate was four hundred millions of years, but he has reached such a point in the calculation that a very small error would make a great difference in the result. From such considerations as these we can understand the uncertainty of any such estimate on present data. It is to be hoped that, in the future, chemical analysts will pay special attention to this problem of the proportion of sodium, and that, in this way, more accurate data may be obtained.

Nor must it be assumed that, however accurate may be the data, this problem can be regarded as solved. There still remain a number of theoretical objections. The method assumes approximate uniformity in this process of the conveying of sodium to the sea. It also assumes that the sodium which reaches the sea never returns to the sedimentaries. Neither of these assumptions, though probable, can be regarded as established. Our knowledge of geological chemistry is certainly not sufficient to enable us to say that none of the sodium in the sedimentaries had its origin in the sea. Then the problem of salt beds must also be considered. That a considerable proportion of the salt deposited in lakes is cyclic, and had its origin in the sea may be regarded as established. But what would happen if such a salt bed were subject to metamorphic action? It is obvious that not only would the sodium enter into the composition of the metamorphic rock, but that it would do so out of all proportion to the chlorine. Such a volatile constituent as chlorine is bound to be evolved in the form of some compound of lower boiling point than salt. Indeed, is it not possible that a proportion of the large quantities of hydrochloric acid, ammonium chloride, and aluminum chloride evolved during volcanic action may have their origin in this manner? If this speculation were true, it is quite possible that the cyclic sodium, using the term in its widest significance, might exceed the cyclic chlorine, and that the calculations would be still further vitiated.

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[1] *Proc. Amsterdam Academy* (1902).

[2] See Clarke, *Data of Geochemistry*, p. 88.

Without laying too great stress on this speculation, it must not be forgotten that uncertainties of this kind exist, and that the sea-salt method must not be regarded as of greater validity than those founded on pure geology. The method is liable to a number of uncertainties and it would not be wise to lay too great stress on this particular estimate. It is highly probable, however, that this method, when based on more accurate analyses, may act as a check on the results obtained from pure geology, from radioactivity, and from other lines of attack. Nor must it be forgotten that this method,[1] even if in the future it should be superseded, was the first serious attempt to get outside the vicious circle of the classical physical three methods, which have proved such a barrier to the progress of geologic thought on this fascinating cosmic problem.

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[1] In making this statement, the interesting investigations of Mr. Mellard Reade on the evolution of carbonate of lime must not be forgotten. This may ultimately prove of greater value than the sea-salt method. Unfortunately, in his later years, this author published other methods, based on less reliable data, which gave a smaller minimum for geologic time. His most valuable work was thus forgotten.